An Introduction to the Earth observing instruments on the Glory mission

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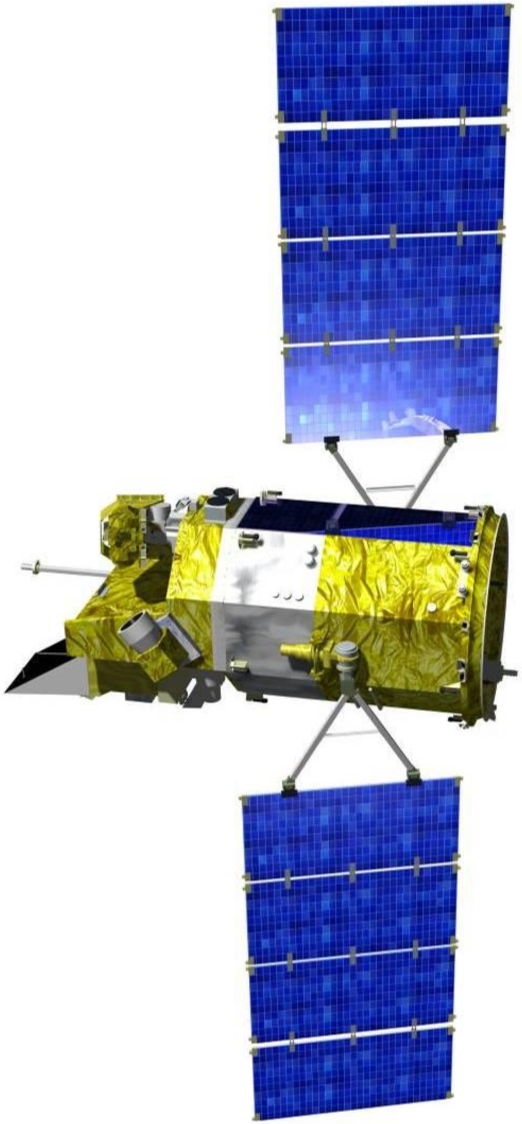
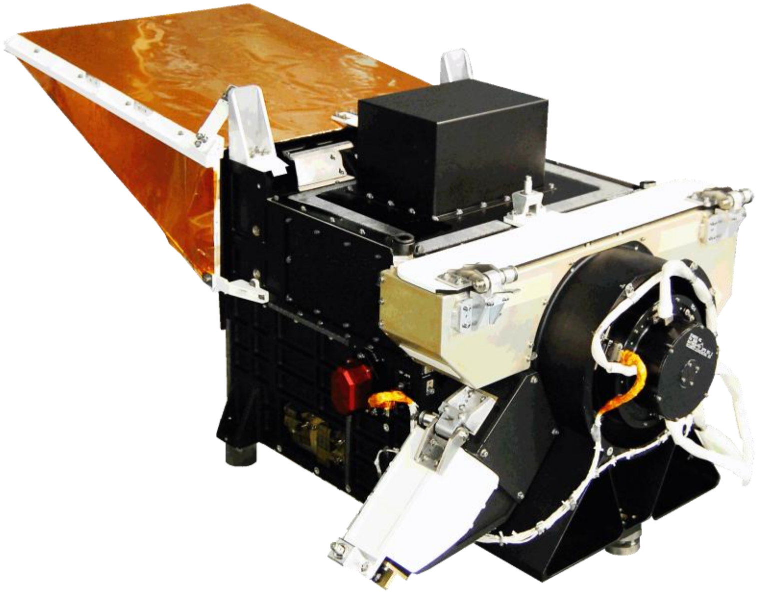
A-train meeting
October 2010

Mission Overview

- Mission Objectives
  – Increase our understanding of aerosols as agents of climate change by flying an Aerosol Polarimetry Sensor (APS), and
  – Continue measuring the sun's direct and indirect effects on climate by flying a Total Irradiance Monitor (TIM) Instrument
- Mission Design
  – 3 years (5 years of consumables)
  – A-train orbit (705 km Altitude, 98.2 degrees inclination; Sun-synchronous)
  – November 2010 launch readiness from Vandenberg Air Force Base (VAFB)

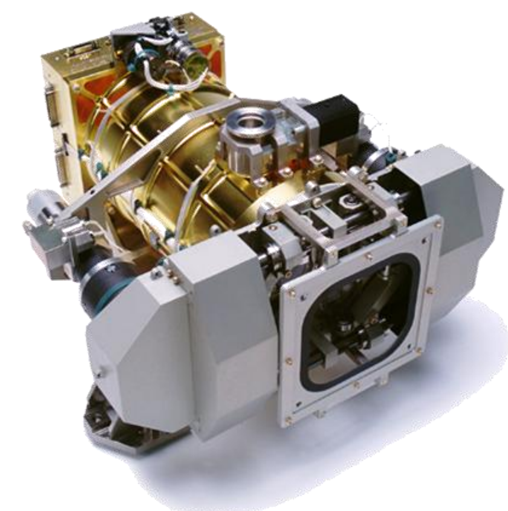


Glory Science Summary

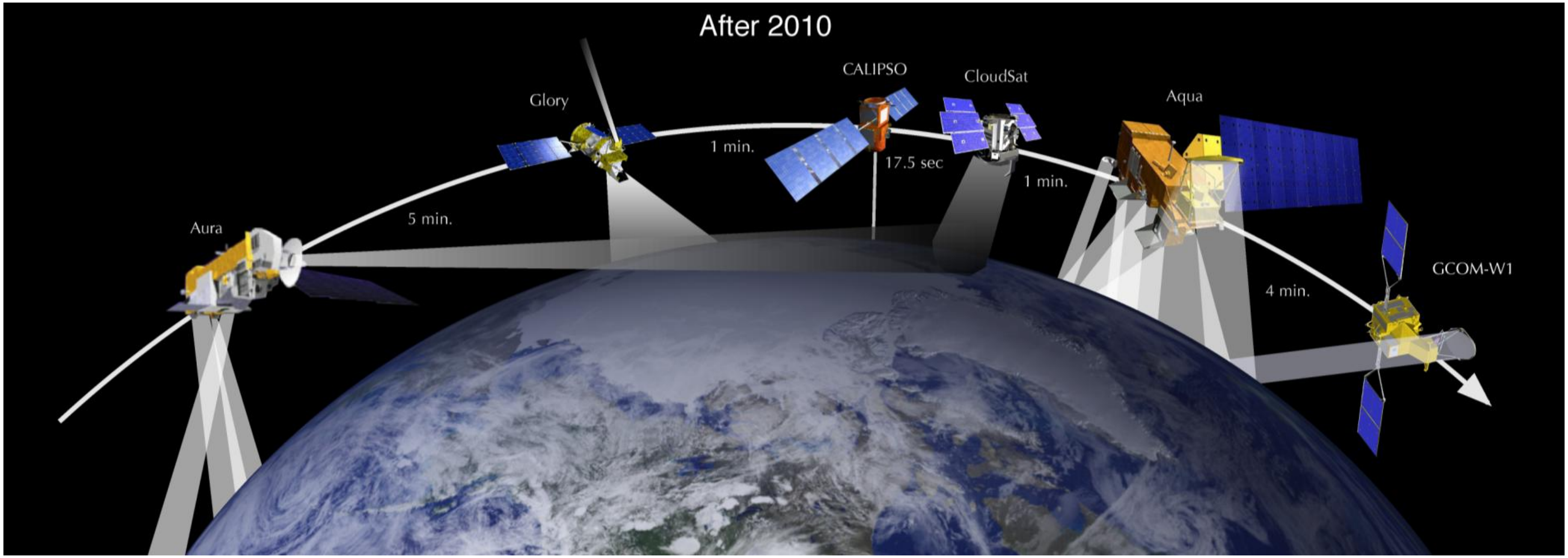


APS will help to quantify the role of aerosols as natural and anthropogenic agents of climate change with much better accuracy than existing instruments

TIM will continue measuring the 30-year record of Total Solar Irradiance (TSI) with improved accuracy and stability to determine its direct and indirect effects on climate



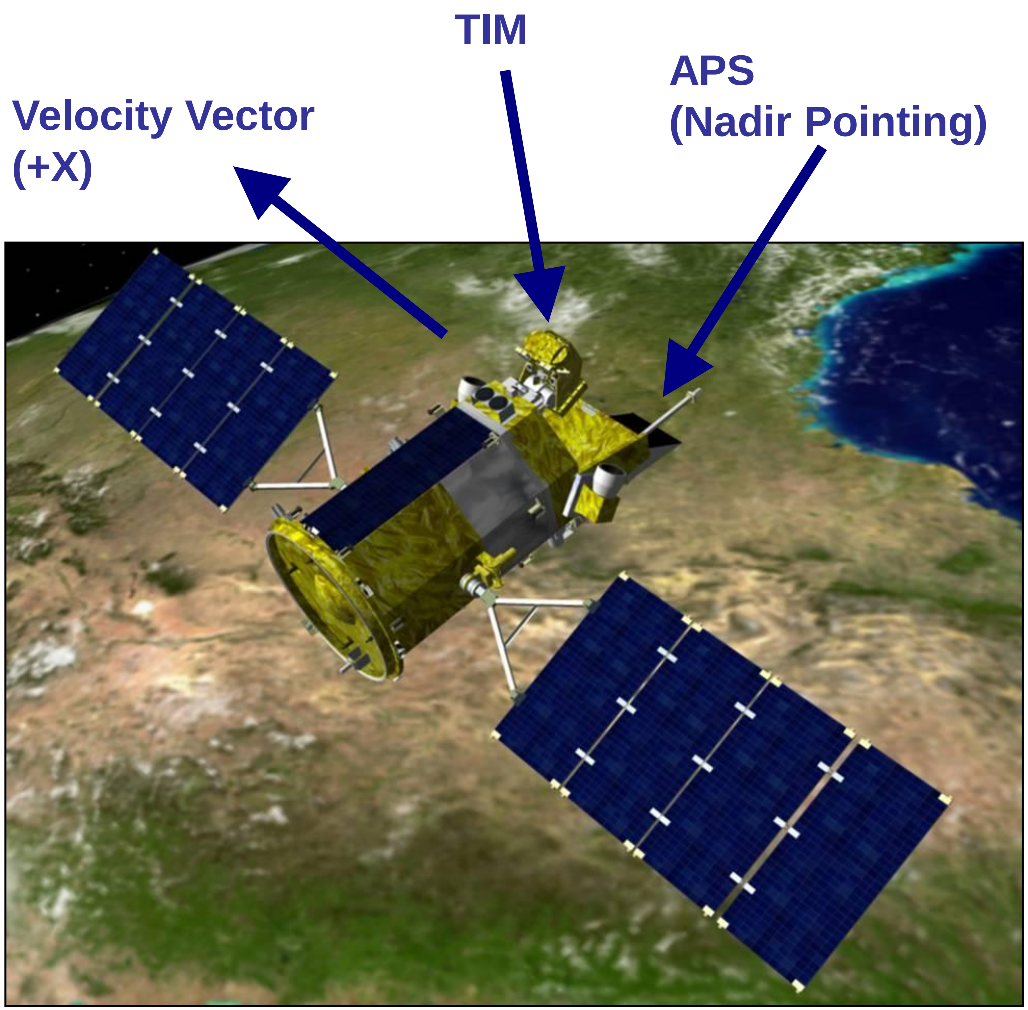
Glory in the A-Train



- Glory will be formation flying with the Afternoon Constellation (A-Train):
  - 705 km orbit altitude / 98.2° inclination (sun-synchronous)
  - Ascending node Mean Local Time (MLT) crossing of ~1:41 pm
  - Position relative to Aqua (based on nominal control box location)
    - ~ 11 minutes behind at MLT crossing
    - 215 km east offset (on WRS-2 grid) -- along track with CALIPSO
- Coincident science observations with CALIPSO / CALIOP and Aqua / MODIS

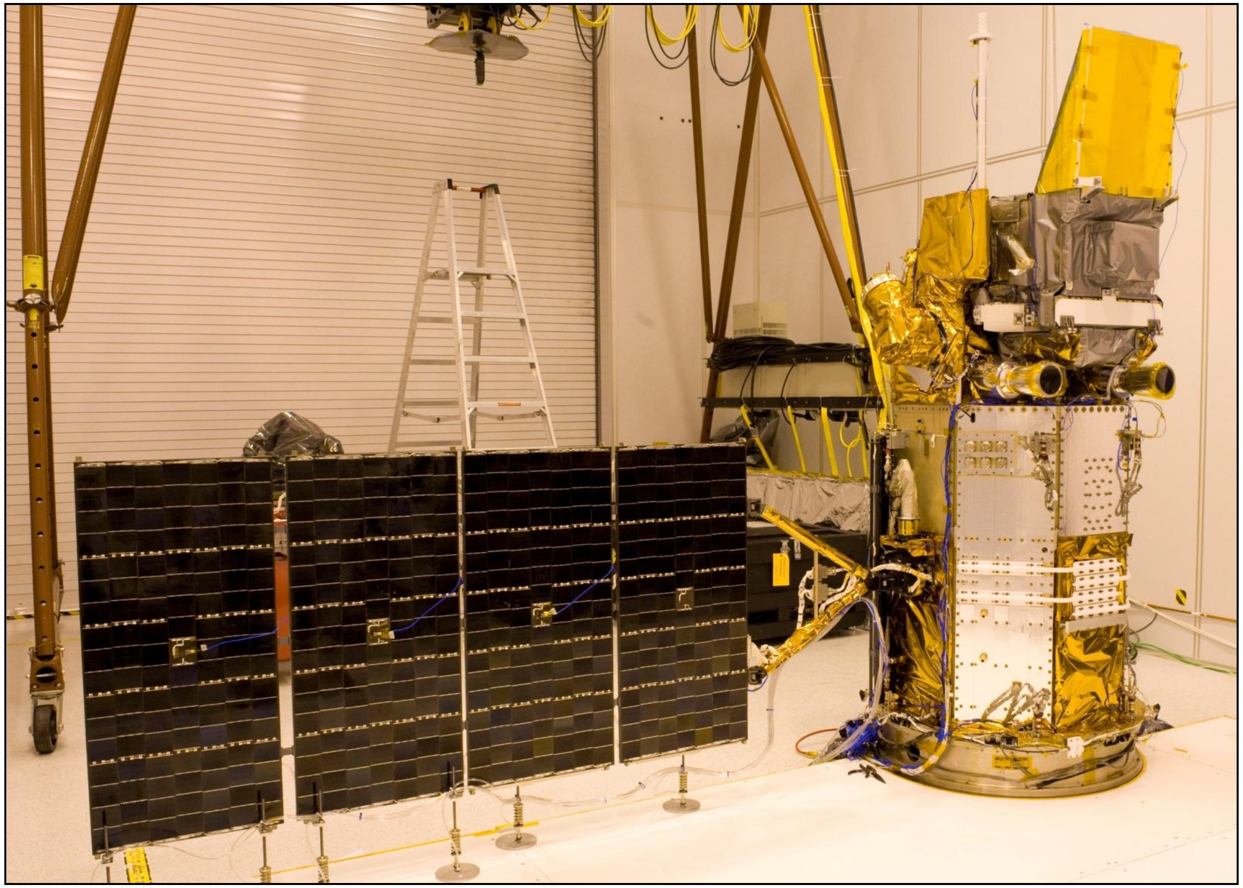
Glory Mission Elements

- Glory nominally oriented with +Z axis nadir
  - Thruster maneuvers, APS glint observations, and calibrations require change in attitude
- APS is an along-track scanner which has it's axes aligned with the spacecraft axes
  - Spacecraft incorporates a yaw bias of 3.2 degrees to account for Earth rotation allowing the APS to see the same scene from multiple (~250) views
- Cloud Camera axes are aligned with spacecraft axes
  - Cross-track, push-broom imager
- TIM system incorporates a gimbaled platform allowing it to track the sun autonomously



Glory Mission Status

- All instruments integrated with the Spacecraft and are performing well
- Spacecraft / Observatory closeout complete and final Thermal Vacuum Test completed in August
- Glory Ground System testing complete and team is conducting Mission Rehearsals
- Launch Vehicle buildup continues and is on track to support Glory launch
- Launch scheduled for February 2011

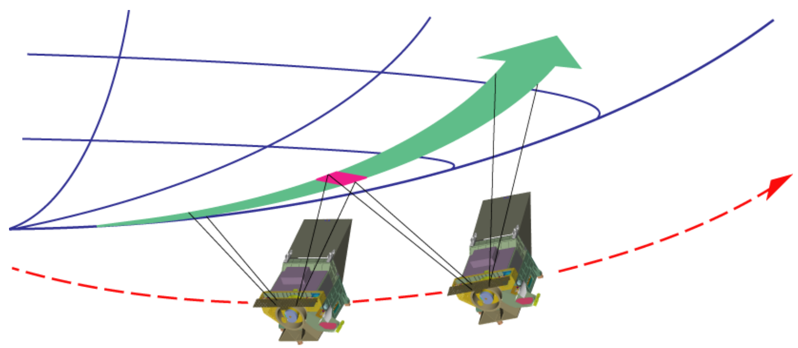


Instruments

Instrument Description – Aerosol Polarimetry Sensor

Capabilities of passive aerosol remote sensing techniques can be classified by:

1. Spectral range (APS: 410-2250 nm)
2. Scattering geometry range (APS: +60°-limb)
3. Number of Stokes parameters (APS: *I, Q, U*)



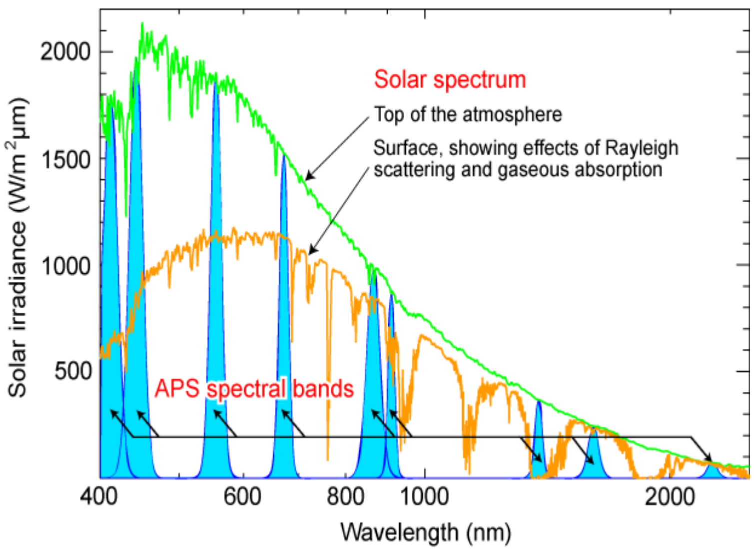
The measurement approach developed for the Glory mission is to use multi-angle multi-spectral polarimetric measurements because:

•Polarization is a relative measurement that can be made extremely accurately.

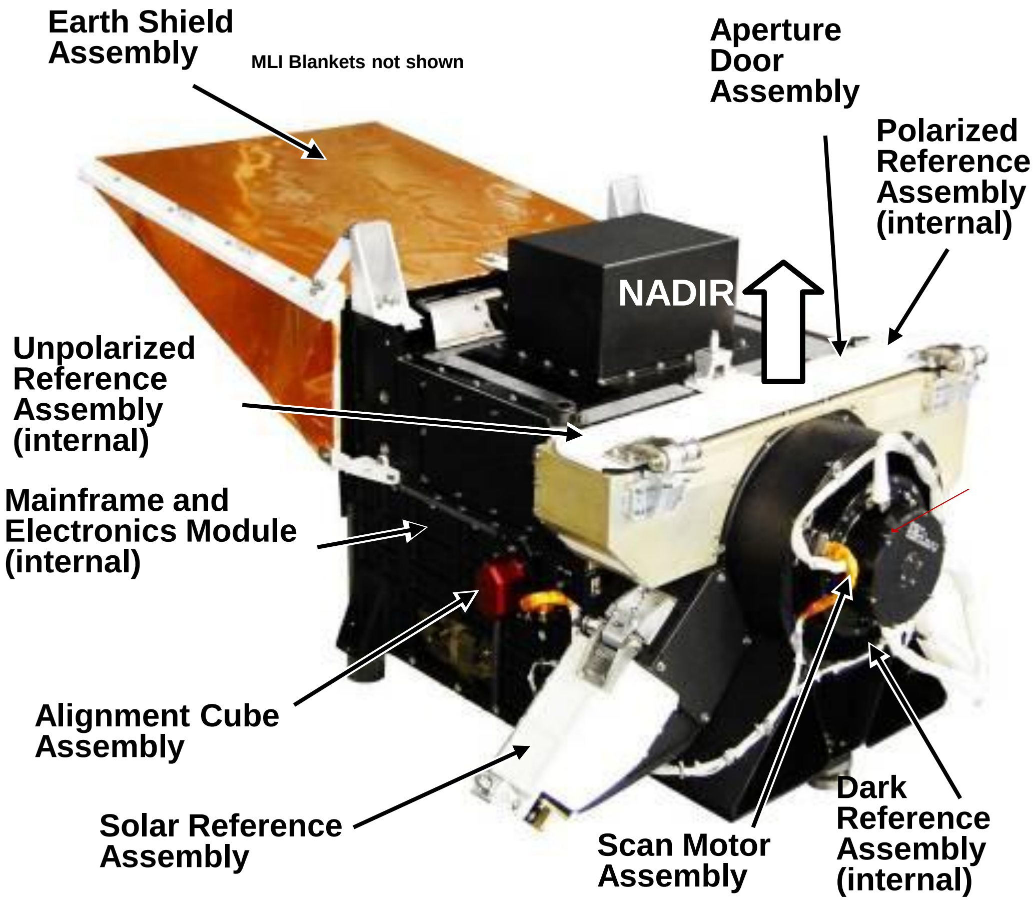
•Polarimetric measurements can be accurately and stably calibrated on orbit.

•The variation of polarization with scattering angle and wavelength allows aerosol particle size, refractive index and shape to be determined.

•Appropriate analysis tools are available.



Instrument Description - APS

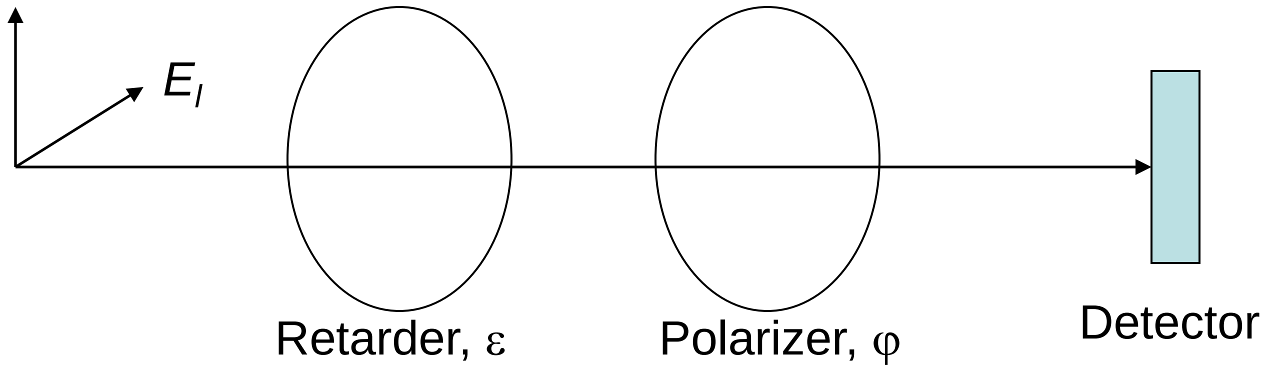


- The Aerosol Polarimetry Sensor (APS) supports a three year NASA mission
  - Measurements of global aerosols in order to reduce the uncertainty in radiative forcing functions
  - Initiation of continuous global monitoring of aerosols in the atmosphere
- The APS instrument description
  - Size: 48 cm x 61 cm x 112 cm
  - Weight: 61kgs (134.2 lbs)
  - Operational Power: 55.0 Watts
  - The APS instrument scans the earth over a nominal field-of-view of +50/-60 degrees about Nadir
  - The APS instrument generates along-track, multiple angle radiometric and polarimetric data with a 5.6 km (8 mrad) circular IFOV
  - APS collects data simultaneously in nine VNIR/SWIR spectral bands and four polarization states
  - APS includes four on-board calibration sources to maintain high polarimetric and radiometric accuracy on-orbit

Instrument Description - APS

How do you measure polarization?

- Use a retarder and a polarizer. V is negligible for solar illumination and Q and U can then be measured just using polarizers.



Stokes Vector

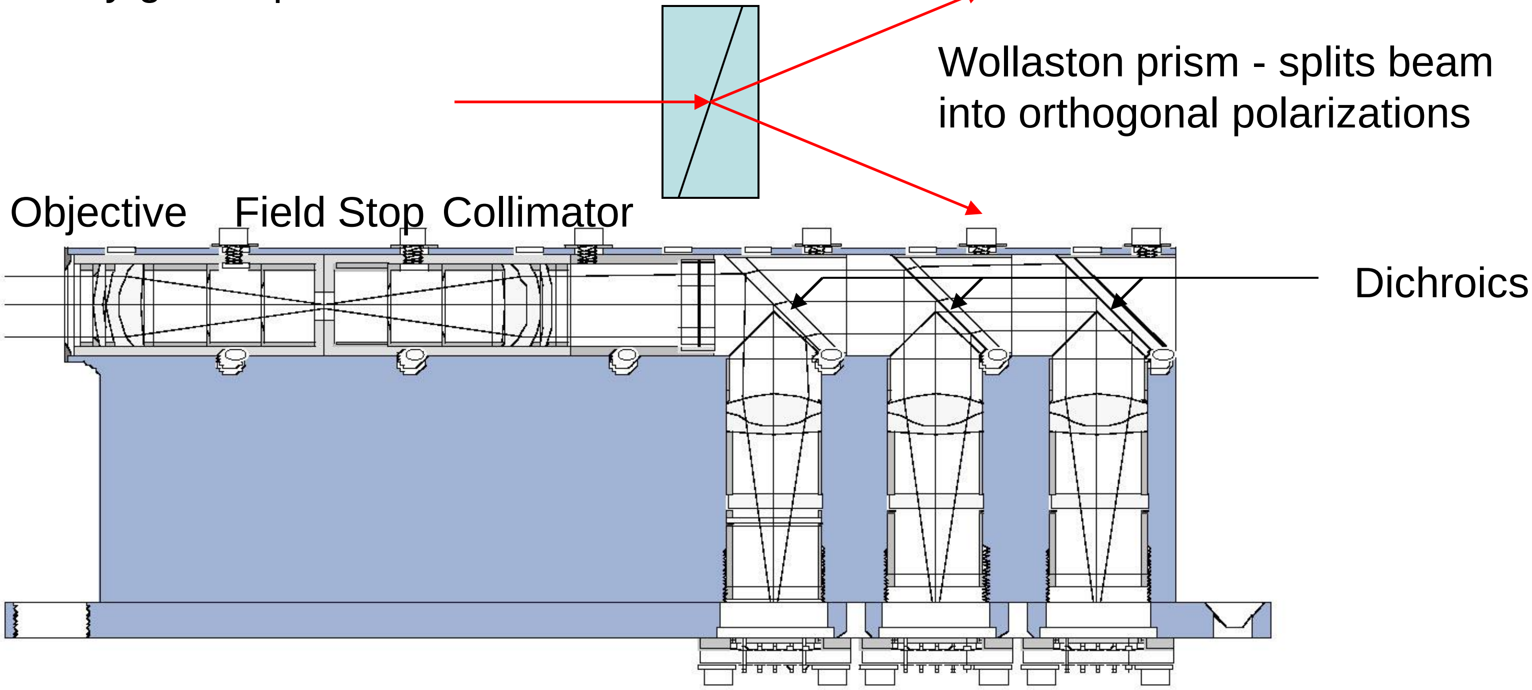
$$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} \langle E_l E_l^* + E_r E_r^* \rangle \\ \langle E_l E_l^* - E_r E_r^* \rangle \\ \langle E_l E_r^* + E_r E_l^* \rangle \\ -i\langle E_l E_r^* - E_r E_l^* \rangle \end{bmatrix} = \begin{bmatrix} \hat{I}(0°,0) + \hat{I}(90°,0) \\ \hat{I}(0°,0) - \hat{I}(90°,0) \\ \hat{I}(45°,0) - \hat{I}(135°,0) \\ \hat{I}(45°,90°) - \hat{I}(135°,90°) \end{bmatrix}$$

$$\mathrm{DoLP} = \frac{\sqrt{Q^2 + U^2}}{I} \quad , \quad \mathrm{AoP} = \tan(2\chi) = U/Q$$

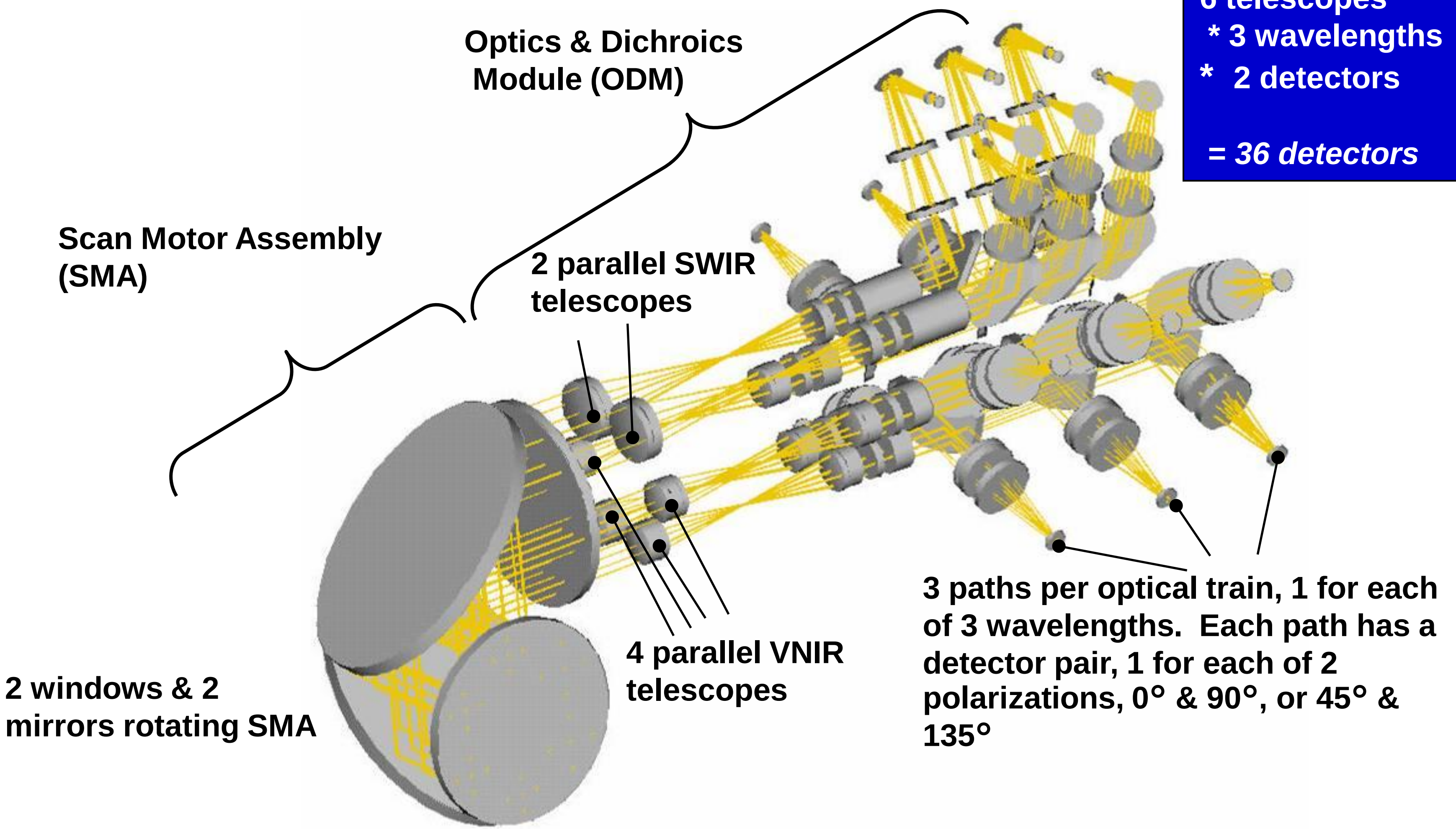
Instrument Description - APS

The APS measurement approach:

- The differences required to calculate Q and U are differences between orthogonal polarization states.
- This can be done very simply using a Wollaston prism in the collimated beam of a relay telescope.
- In APS one telescope measures I and Q in three spectral bands and a second telescope measures I and U in the same spectral bands.
- The measurements of intensity are therefore redundant and if a single channel in any given spectral band is lost this does not affect the APS data.



Instrument Description - APS



6 telescopes
*** 3 wavelengths**
*** 2 detectors**

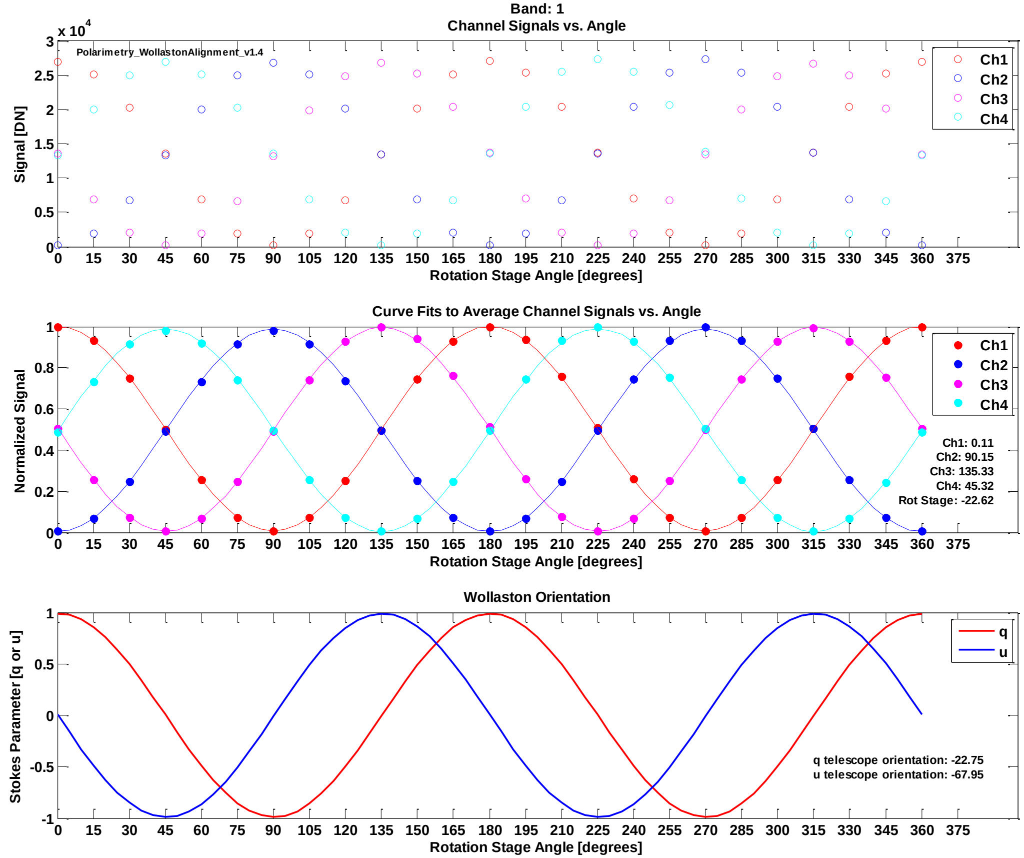
= 36 detectors

- Each pair of telescopes gives I, Q and U in three bands. APS has three pairs of telescopes giving I, Q and U in nine spectral bands at 410, 443, 555, 673, 865, 910 (VNIR), 1378, 1605 and 2250 (SWIR) nm.

Instrument Description - APS

Correcting for imperfections:

- In practice the polarization orientations of the Wollaston prisms in the telescopes measuring Q and U are not exactly 45° from one another.
- This "clocking error" is measured at ambient, pre- and post-vibe and during TVAC.
- No change of the orientation of the Wollastons has been detected, above the 0.02° uncertainty with which that angle can be determined.



Wollaston Orientations

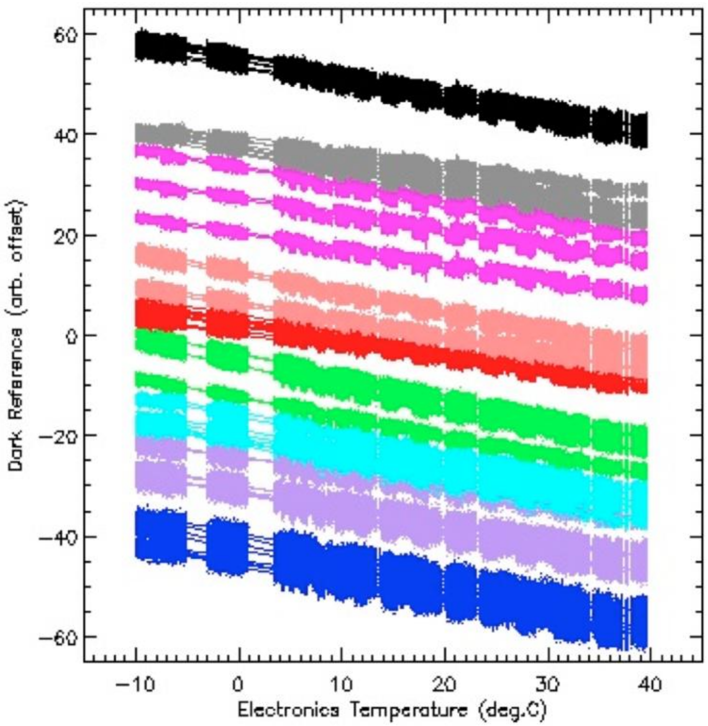
Q-U Telescope Pair	Relative Clocking Error [deg]	Uncertainty [deg] Reqt: <0.05
VNA1 / VNA2	0.190	0.018
VNB1 / VNB2	-0.405	0.015
SW1 / SW2	0.181	0.014

Absolute Orientation

Telescope	Orientation [deg]	Uncertainty [deg] Reqt: <0.10
VNA1	-22.754	0.024
VNA2	-67.947	0.024
VNB1	-23.166	0.025
VNB2	-67.761	0.025
SW1	-22.824	0.024
SW2	-68.006	0.024

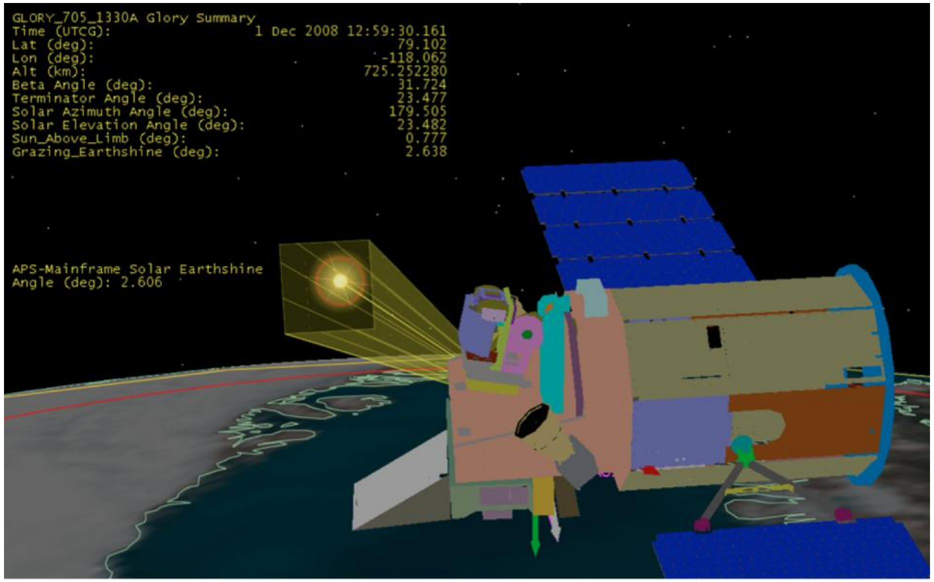
Instrument Description - APS

- The APS has four calibrators/reference assemblies that are viewed during each scan
  - **Dark Reference Assembly (DRA)**:
    - Provides robust measure of dark with the contamination of less than 0.005% of scene radiance when the APS aperture is flood illuminated in the near field.
    - Dependence on electronics temperature of dark reference level of around -0.3 DN/° C (small differences between bands) with stability of this temperature dependence of 0.01 DN/° C.



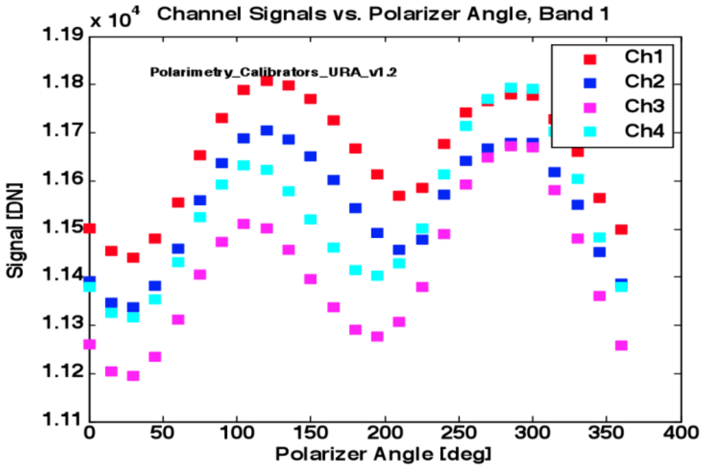
Instrument Description - APS

- The APS has four calibrators/reference assemblies that are viewed during each scan
  - **Solar Reference Assembly (SRA)**:
    - The solar reference assembly has a one time deployable door to protect the Spectralon™ until a solar and lunar calibration can be performed within a few orbits.
    - A Spectralon™ reflectance plaque provides the initial definition of absolute reflectance scale.
    - Reflectance calibration is subsequently tracked by monthly lunar calibration maneuvers.
    - A 3° yaw allows the direct solar beam to illuminate the Spectralon™ with an elevation of 23.5°.



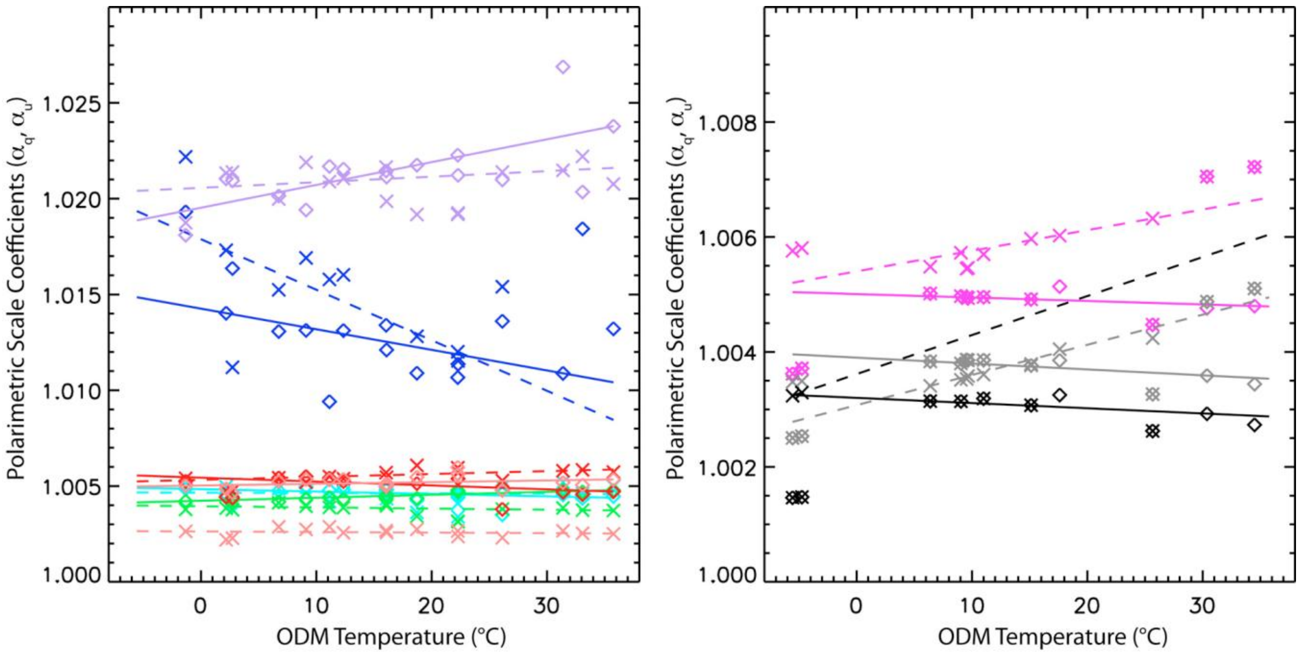
Instrument Description - APS

- The APS has four calibrators/reference assemblies that are viewed during each scan
  - **Unpolarized Reference Assembly (URA):**
    - The URA provides a depolarized view for all of the detectors by means of a polarization scrambler composed of two wedges of crystalline quartz with the optical axes orientated 45° to each other – a spatially varying retardance is created which scrambles any scene polarization. An additional flat fused silica element is used to reduce the effects of reflections.
    - The URA views the same scene as the APS nadir view providing similar dynamic range and spectral content for the calibration measurements and the scene data.
    - The worst case URA performance was for the 673 nm band where 100% polarized light was reduced to 0.8% (median of 0.3%).



Instrument Description - APS

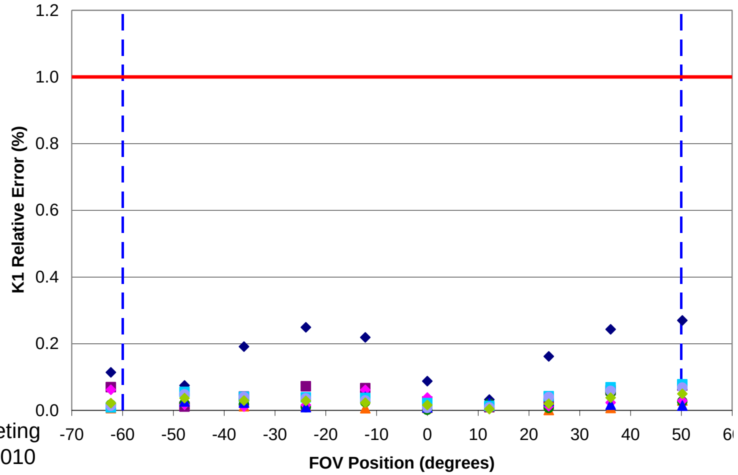
- The APS has four calibrators/reference assemblies that are viewed during each scan
  - **Polarized Reference Assembly (PRA):**
    - The PRA provides a strongly polarized calibration scene by using Glan-Taylor polarizers for each VNIR telescope and a wire grid polarizer for the SWIR detectors.
    - This allows any depolarization of the incident light by the sensor to be tracked and corrected.
    - Blue and mauve points in left hand figure are scattered because of low noise. Small temperature dependence in depolarization of SWIR measurements of U is apparent in the right hand figure.



Instrument Description - APS

- The APS scanner uses a pair "crossed" mirrors with constant angle of incidence over the entire scan:
  - "Crossed" mirrors operate such that if light has an s-polarized reflection at the first mirror it will have a p-polarized reflection at the second mirror and vice versa.
  - 255 scene views are recorded by APS. Only the views from 8-255 are unvignetted in all telescopes.
  - Scene 8 has a view angle of +50° at the spacecraft which corresponds to +60° at the surface of the Earth from 705 km.
  - Scenes 253-255 are viewing the limb of the Earth and do not intersect with the surface. These limb views provide scenes that are dominated by Rayleigh scattering for a cross-check of polarimetric calibration.
  - Measured Response Versus Scan (RVS) variations in polarimetric and radiometric performance are small.
    - The table below gives worst case performance and is an upper bound on radiometric RVS variations since the integrating sphere will also have variations of this order in its output over the period of the test.
    - Only the 410 nm band requires small instrumental polarization corrections

Band	RVS_i1	RVS_i2	RVS_p
1	0.16%	0.17%	0.09%
2	0.12%	0.28%	0.08%
3	0.11%	0.09%	0.04%
4	0.15%	0.18%	0.06%
5	0.21%	0.22%	0.07%
6	0.21%	0.21%	0.08%
7	0.19%	0.24%	0.09%
8	0.14%	0.21%	0.12%
9	0.25%	0.26%	0.09%

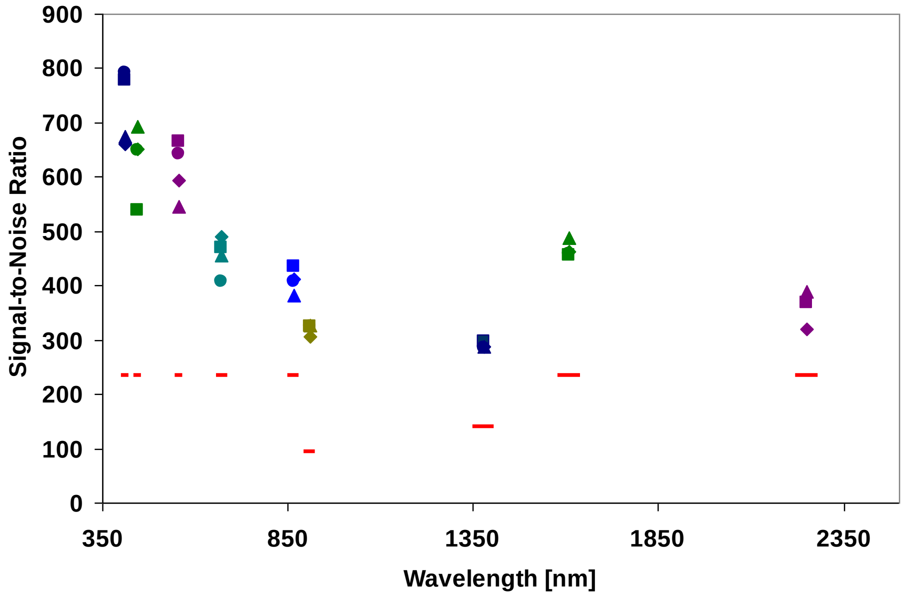


Instrument Description - APS

- APS noise:
  - Is well modeled as Noise_Power = Floor + Shot*Signal:
    - In units of DN this model has the parameters given below:

	Band								
	410	443	555	670	865	910	1378	1610	2250
Floor	42.2990	41.0747	16.2897	13.5077	8.6873	20.5268	10.2917	7.0373	12.3837
Shot	0.0049	0.0049	0.0031	0.0028	0.0026	0.0042	0.0233	0.0033	0.0052

- APS SNR:
  - Signal to noise ratio requirements were specified for a typical moderate aerosol load over the ocean

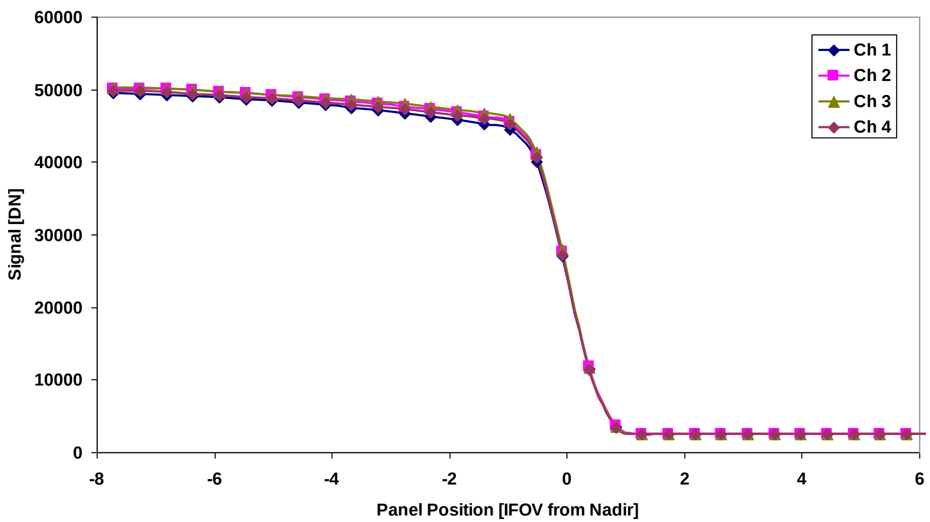


Instrument Description - APS

- APS linearity:
  - Measured using delta transmission over the full dynamic range available from the integrating sphere:

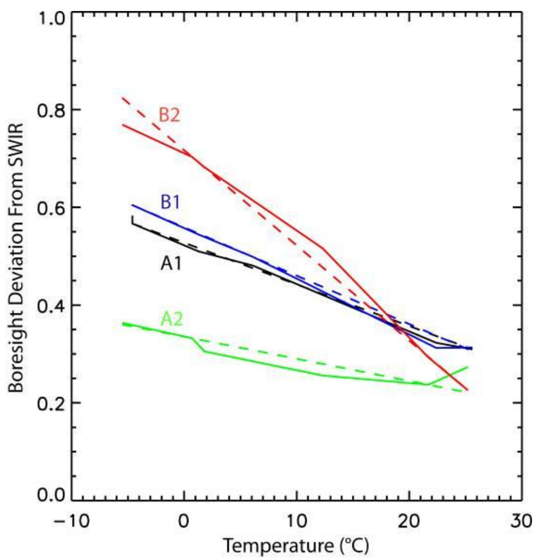
Band	Req't	Channel			
		1	2	3	4
1	0.07	0.004	0.009	0.006	0.005
2	0.07	0.003	0.005	0.004	0.001
3	0.07	0.017	0.016	0.018	0.015
4	0.07	0.023	0.021	0.022	0.023
5	0.07	0.023	0.025	0.026	0.026
6	0.07	0.019	0.021	0.020	0.020
7	0.07	0.023	0.021	0.020	0.019
8	0.07	0.013	0.014	0.016	0.013
9	0.07	0.039	0.044	0.040	0.037

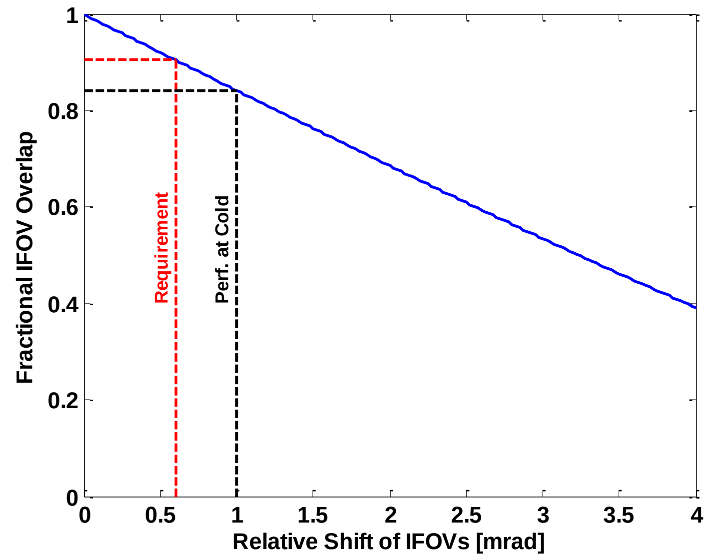
- APS stray light:
  - Spectralon plaque with a radiance level with an LER of unity for overhead sun:



Instrument Description - APS

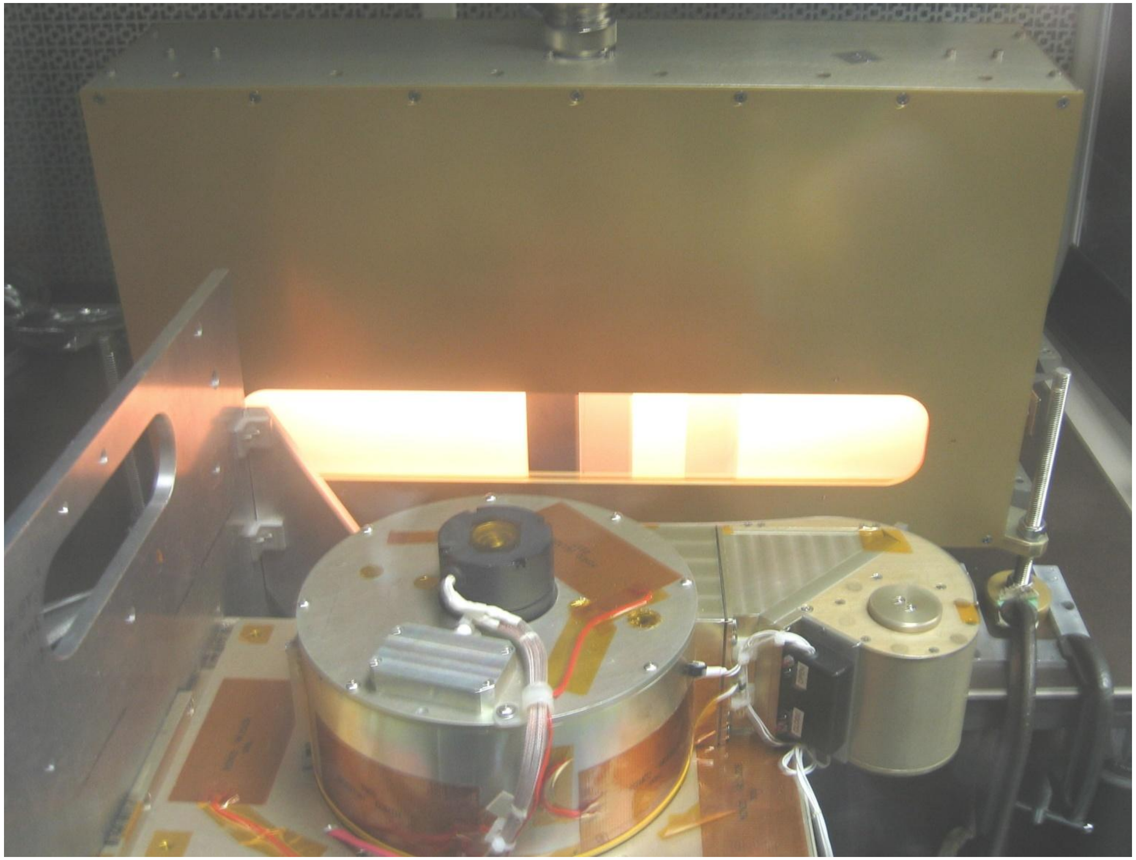
- APS pointing:
  - The fields of view of the APS telescopes exhibit small shifts with respect to one another as a function of temperature
  - The operating temperature of the APS optics on orbit is expected to be around 15° C which will meet the required co-alignment
  - At cold temperatures the IFOV co-alignment will be worse. This leads to random errors when using the longer wavelength bands to characterize land surfaces, but not bias errors. Increased measurement uncertainty is captured in retrieval errors.



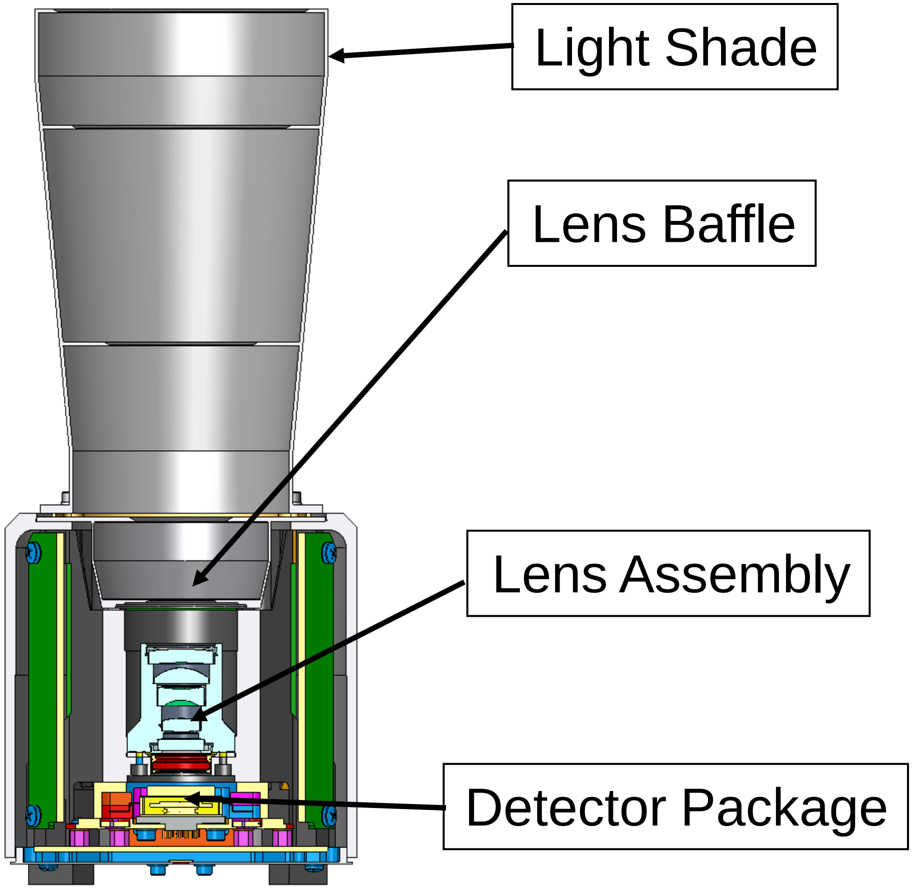


Instrument Description - APS

- APS performance on the spacecraft:
  - APS performance was tracked during spacecraft thermal/vacuum testing using an extended field source that provided illumination of the URA, PRA together with four polarized and one unpolarized view over the scene view range.
  - APS polarimetric performance was stable at the 0.1% level throughout TVAC testing.



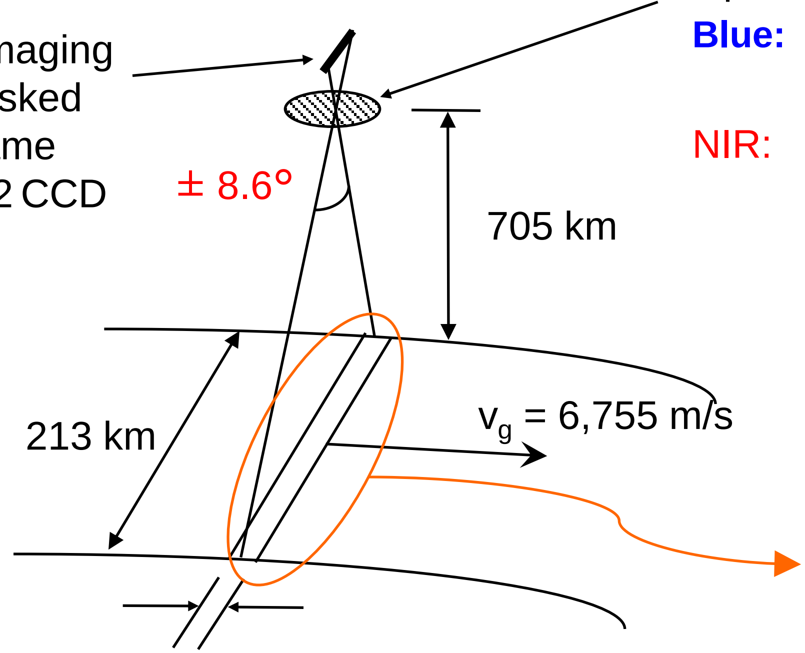
Instrument Description – Cloud Cameras



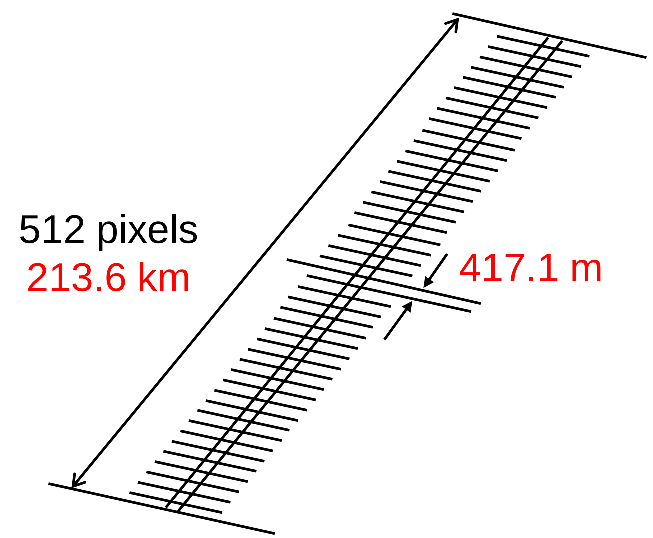
- The Cloud Cameras on Glory provide higher spatial resolution sub-pixel cloud identification within the APS FOV.
  - Two cameras, one with a band at 443 nm and one with a band at 865 nm. 2.8 kg, 10.3 W/camera.
  - Spatial resolution of 420 m with 200 km swath.

Instrument Description – CC

512 x 1 imaging from masked full-frame 512 x 512 CCD



Optics:	f/4.1 lens system
Blue:	**EFL = 40.733 ± 0.01 mm (ΔT: -20 to +45°C)**
	λ_c: 443 ± 3.0 nm; $FWHM_{0°}$ = 16 ± 3.0 nm
NIR:	EFL = 40.561 ± 0.016 mm (ΔT: -20 to +45°C)
	λ_c: 864.7 nm -3.9 nm / +0.0 nm;
	FWHM = 31.2 nm



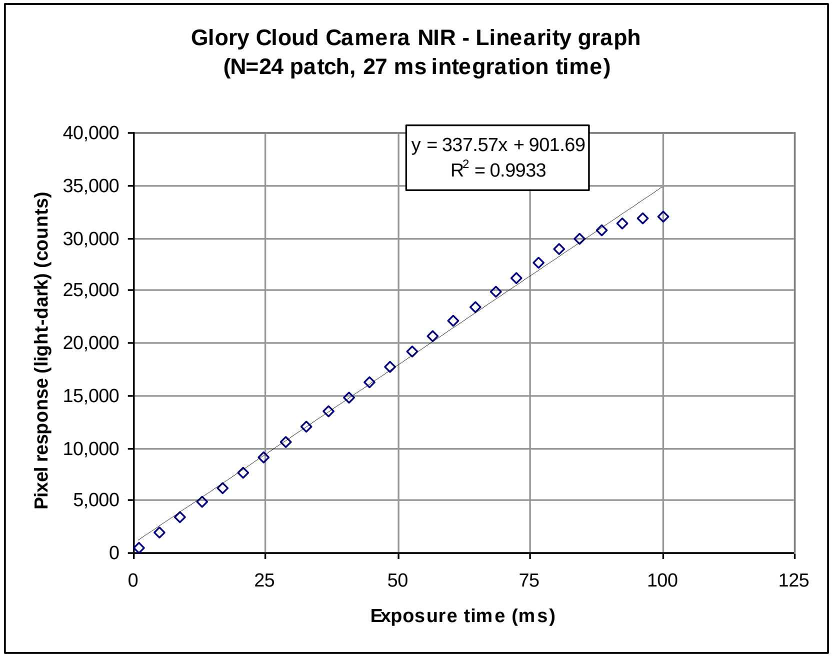
182 m per 27.008 ms exposure time (443 nm)
142 m per 20.996 ms exposure time (865 nm)
(down-track image smear)

Instrument Description – CC

- CC stray-light performance:
  - Less than 1% at 2 pixels from a bright source.

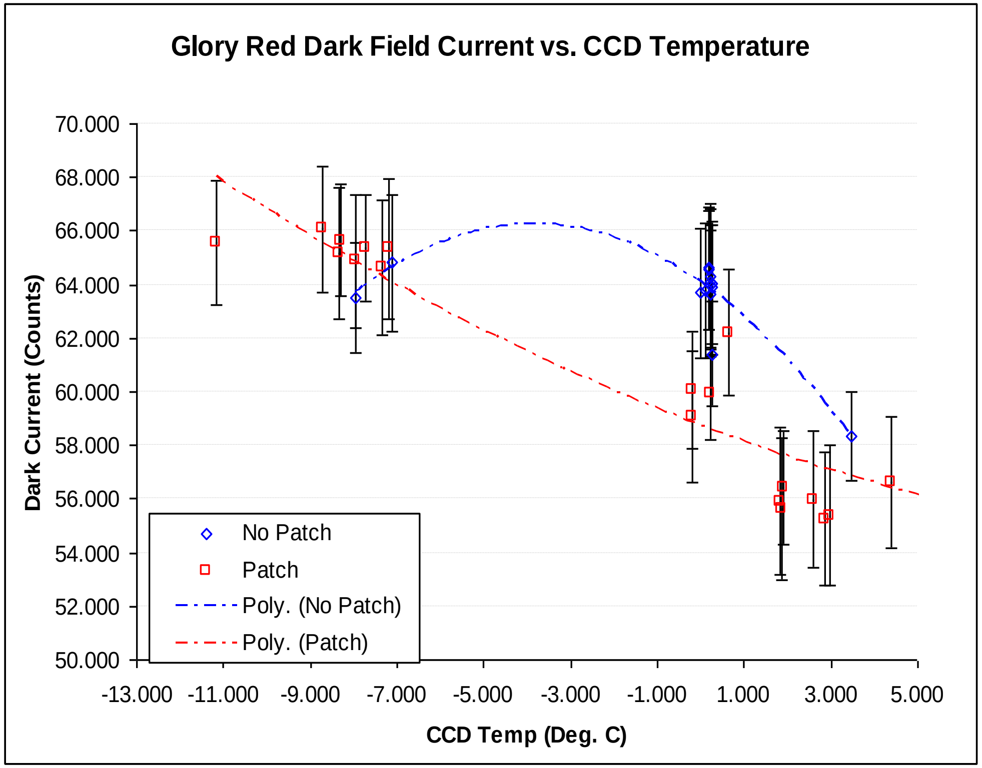
5	22	55	29	6
14	183	1,031	295	24
21	409	7,919	841	39
12	108	453	166	18
3	11	26	15	4

- CC linearity:
  - Less than 0.9% deviation from linearity over entire dynamic range. Max deviation occurs at minimum radiance level.

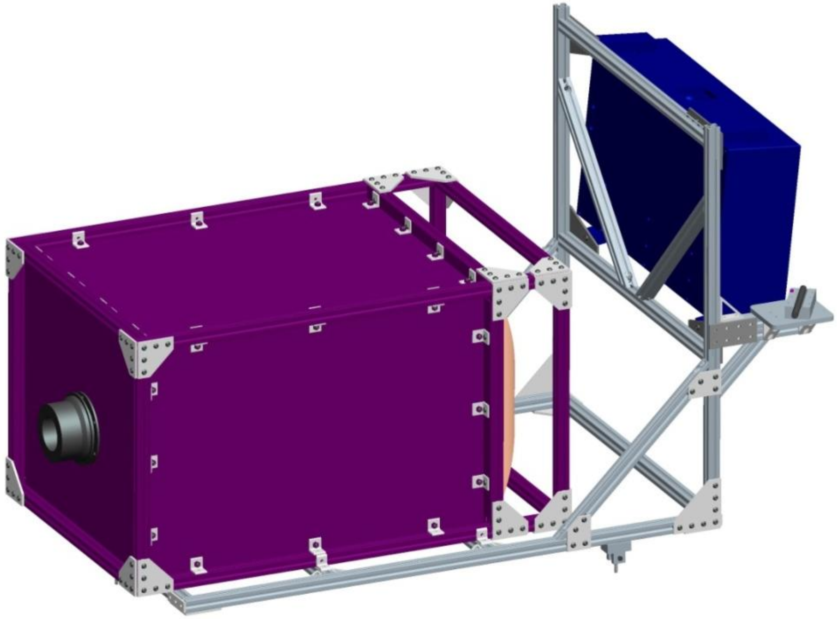


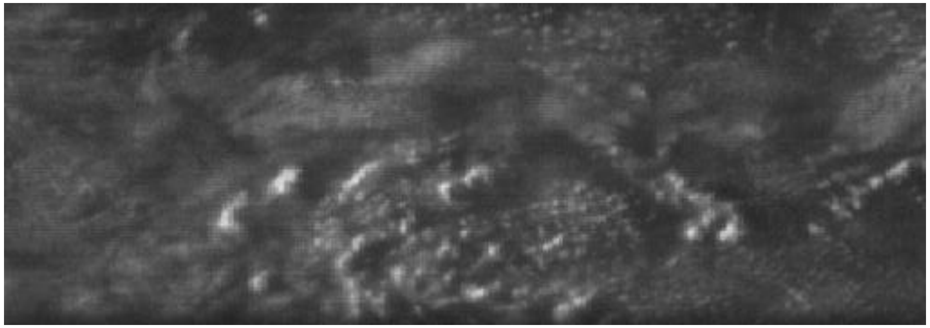
Instrument Description – CC

- CC noise performance:
  - At L_{typ} shot noise is 197e$^-$ and 157e$^-$ with 2e$^-$ of dark noise which yields SNR of 172 and 135 respectively (LER at L_{typ} is 0.07 and 0.04 for overhead sun).
  - Dark noise increases by 6e$^-$/year. Dark reference measurements required to evaluate pixel degradation.
- CC dark values:
  - Dark reference values track with temperature



Instrument Description – CC



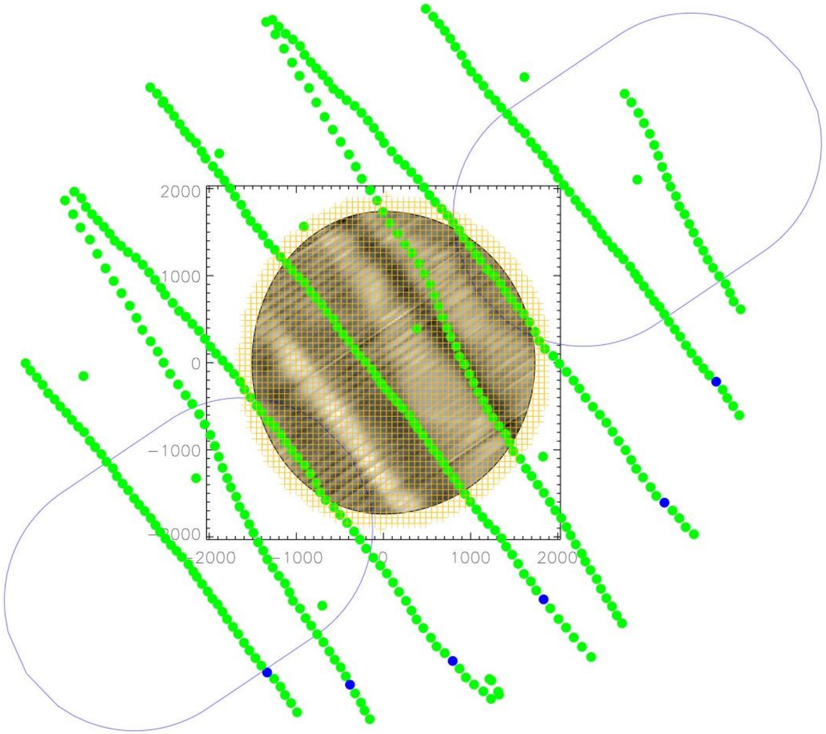


- The data from the cloud cameras is compressed.
  - To provide an end-to-end test of spacecraft compression and ground system decompression we used an “Ansell Adams” camera working backwards
  - A computer monitor was put in the back focal plane of a F11/760 mm Nikkor Apo-chromat
  - We played a movie of MODIS cloud data to the blue camera and checked the compression results.

Mission Maneuvers

Mission Maneuvers

- Mission Maneuvers
  - Lunar calibration
    - Spacecraft rolls to view the moon at a lunar phase close to 24° .
    - APS scan is micro-stepped across the moon in the cross-track direction three times as the FOV advances 6 mrad in the along track direction
    - This allows a uniform aperture (peak-to-peak 2%, integral 0.1%) that is larger than the moon to be synthesized



Mission Maneuvers

- Mission Maneuvers
  - Solar Calibration
    - 3° yaw as the spacecraft comes over the pole allows the sun to enter the solar reference assembly while the Earth is in eclipse
  - Cloud Camera Dark Calibration
    - Spacecraft rolls to 10° above the Earth limb on the dark side of an orbit.
  - Glint Roll
    - The spacecraft rolls to view the glint over the ocean. The roll that is allowed is from 30° W to 10° E.
    - Since the A-train is an afternoon orbit rolls will generally be somewhere between 10 and 20° to get close to glint.
    - The Glory science team will be provided with an interface at http://glory.giss.nasa.gov to nominate glint/roll locations.
      - Nominally glint rolls will focus on the North Atlantic in summer, North Pacific in spring, South Atlantic in winter and the South Pacific in fall.

Existing Data

- The Research Scanning Polarimeter has served as a precursor to APS on the NASA Glory mission and a testbed for the development of retrieval algorithms
  - Polarization insensitive scanner: 152 scene sectors over 121 degrees of scan (+/-60° from the normal) + 10 dark scenes + 10 in-flight calibrator views
  - Measures total and linearly polarized reflectance *(I, Q, U)* in 9 spectral bands (410, 470, 555, 670, 865, 960, 1590, 1880 nm and 2.25 µm. Only differences with APS are at 470 (443), 960 (910), 1880 (1378) where the parenthetic values are for APS bands
  - 0.2% polarimetric accuracy
  - Columnar Aerosol retrievals
    - Optical depth
    - Size distribution
    - Refractive index
  - Cloud retrievals
    - Optical depth
    - Effective radius, variance
    - Cloud top heights
    - Liquid water path

Existing Data at ftp://ftp.giss.nasa.gov/outgoing/rsp

- ALIVE:
  - ARM CF, Southern Great Plains, aerosol retrievals, surface characterization, September 2005
- MILAGRO/INTEX-B:
  - Mexico City and Gulf of Mexico, March 2006
- ARCTAS:
  - Canadian forest fires near Yellowknife, June / July 2008
- RACORO:
  - ARM CF, Southern Great Plains, cloud physics retrievals, June 2009
- CalNEX:
  - Urban pollution over LA, clouds off-shore in co-ordination with NOAA-P3, May 2010
- CARES:
  - Characterization of snow polarized BRDF with plan for aerosol retrievals over snow. Outflow from Sacramento, June 2010
- COCOA
  - Saharan dust in the Caribbean August 2010

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http://glory.giss.nasa.gov/

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Glory is a remote-sensing Earth-orbiting observatory designed to achieve two separate mission objectives. One is to collect data on the chemical, microphysical, and optical properties, and spatial and temporal distributions of aerosols. The other is to continue collection of total solar irradiance data for the long-term climate record.

The Glory mission's scientific objectives are met by implementing two separate science instruments, one with the ability to collect polarimetric measurements along the satellite ground track within the solar reflective spectral region (0.4 to 2.4 micrometers) and one with the ability to monitor changes in sunlight incident on the Earth's atmosphere by collecting high accuracy, high precision measurements of total solar irradiance. Glory accomplishes these objectives by deploying two instruments aboard a low earth orbit satellite, the **Aerosol Polarimetry Sensor** (**APS**) and the **Total Irradiance Monitor** (**TIM**). Additionally, a cloud camera system will provide images that allow the APS scans along the spacecraft ground track to be put into spatial context and to facilitate determination of cloud occurrence within the APS instantaneous field of view.

NASA Video

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